AN OBJECTIVE METHOD OF FORECASTING SUMMER PRECIPITATION AT SALT LAKE CITY, UTAH

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ABSTRACT

An attempt is made to develop an objective method of forecasting summer precipitation at Salt Lake City, using moisture variables on a scatter diagram. These variables are surface dew point at Salt Lake City vs. the minimum temperature-dew-point spread between 700 and 500 mb. at a nearby raob station selected according to the 12,000-foot wind direction at Salt Lake City. Probability lines for the occurrence of both measurable rain and a trace or more are drawn. Skill scores and percentage of correct forecasts are computed for both original and test data and compared with Weather Bureau staff forecasts.

CONTENTS

INTRODUCTION

Forecasting the occurrence of summer precipitation in Utah, as well as in other dry climates, has often proved difficult, for rainfall is usually dependent on relatively narrow tongues of moisture protruding into the State from a southerly direction. Since several rather successful objective methods for forecasting precipitation at Pacific Coast stations and other points have been developed in the past few years, it was felt that a similar study undertaken for Salt Lake City might produce useful results.

Carpenter [1] used 700-mb. mixing ratios and relative humidities to forecast precipitation in Utah for all seasons. Most authors, as Brown [2], Vernon [3], Counts [4], and Jorgensen [5] have used rather extensive and elaborate typing systems in the development of their methods. Angell and Chen [6], on the other hand, in their report on forecasting rainfall at Los Angeles, reach the conclusion that a relatively simple forecasting system with a limited number of parameters yields results approximately equal to those of a highly complicated and time consuming typing system. Also, Price [7] obtained reasonably good results using a simple approach to forecasting thunderstorms at Washington. Therefore, since the time available for the study was somewhat limited, no attempt was made to undertake any extensive map typing, and the general procedure followed was to test the forecasting significance of numerous pertinent parameters by means of scatter diagrams.

At first the study was to include precipitation for all of the warm season, May through September. However, because it was quickly ascertained that July and August rainfall is generally of quite a different origin than May, June, and September precipitation, the field for consideration was narrowed to the midsummer months. In July and August, rainfall is usually associated with tongues of moist air moving into Utah from a southerly direction around the west side of a high-level anticyclone situated over the south-central portion of the United States. In May, June, and September, however, in addition to the above, precipitation also accompanies frontal activity and cold Lows aloft. Very few significant fronts pass Salt Lake City from the west or northwest in midsummer, and most of these are "dry" fronts accompanied by little or no rain. Cold Lows aloft over or near northern Utah during the midsummer period under study were practically nonexistent. Thus, the relatively uncomplicated synoptic situations associated with midsummer rainfall at Salt Lake City were found to lend themselves fairly well to the application of objective forecasting techniques.

DATA

Data for July and August 1946 through 1949, as well as Weather Bureau Provisional Forecast Rating forms for checking accuracy of results against the Salt Lake City official staff forecasts, were available for the study. Use of earlier data was precluded by the absence of Las Vegas radiosonde observations, which were not begun until September 1945. Records for 5 of the available 8 months were used for the original data, and records for 3 months—July 1946, August 1948, and July 1949—were set aside for test data. The data were so divided that wet and dry months were represented in each sample and at least one July and one August was reserved for the test sample.

The period 1130 MST to 0530 MST the following day was chosen as the forecast period for the following reasons: (1) Most telephone calls to the Weather Bureau for weather information are received in the morning, and the question most frequently asked is, "Will it rain today or tonight?" (2) The morning forecast gets the best distribution to newspapers, radio stations, and wire service news agencies. (3) Most summer precipitation falls in the afternoon or evening, with very little falling during the six-hour period from 0530 to 1130 MST.

The latest available data for the forecast are the 0530 MST surface weather map, the 0230 MST pibal chart and the 2030 MST previous evening raobs and upper air charts. In actual practice the forecast can be made as soon as the 0530 MST synoptic report for Salt Lake City is available.

VARIABLES

Numerous variables that were believed to be significant in forecasting rainfall at Salt Lake City were tested. These are listed below:

A. Circulation variables:
- Sea level pressure at Salt Lake City.
- 850-mb. height at Salt Lake City.
- 10,000-, 12,000-, and 14,000-foot winds at Ely, Las Vegas, and Salt Lake City.
- 700- and 500-mb. contour flow.
- 700- and 500-mb. heights and height differences at Ely and Las Vegas.

B. Moisture variables:
- Surface dew point at Salt Lake City.
- Surface wet-bulb temperature at Salt Lake City.
- 700- and 500-mb. dew point at Las Vegas, Ely, Grand Junction, Boise, and Lander.
- Minimum temperature-dew point spread between 700- and 500-mb. at Las Vegas, Ely, Boise, Lander, and Grand Junction.

C. Stability variables:
- 700- and 500-mb. temperatures at Las Vegas and Ely.
- Temperature difference, 700–500-mb., at Las Vegas and Ely.

In addition, 3-hourly surface pressure tendencies at Salt Lake City were tested.

Of all these, the moisture variables played by far the dominating role, with circulation next in importance. Stability appeared to play a less important role; in fact, the air over the Plateau in midsummer is nearly always conditionally and frequently convectively unstable. The 3-hourly surface pressure tendency at Salt Lake City proved to be of no value because precipitation was usually not associated with moving troughs or fronts.

In the final selection of moisture variables, one parameter was chosen to indicate moisture already present at Salt Lake City, and another to indicate whether moist or dry air would move into the area during the forecast period. As indicators of moisture already present, the 0530 MST dew-point and wet-bulb temperatures both showed good correlation with the occurrence or nonoccurrence of precipitation. The dew point was selected because it correlated slightly better than the wet-bulb temperature, had a wider range, and appears in the regular synoptic report. Table 1 shows the frequency distribution of rainfall occurrence with the Salt Lake City dew point.

TABLE 1.—*Frequency of occurrence of measurable rainfall and trace or more with the 0530 MST dew point at Salt Lake City*

Salt Lake City 0530 MST dew point (° F.)	Total cases	Cases with 0.01 inch or more	Percentage frequency	Cases with trace or more	Percentage frequency
61–65	4	4	100	4	100
56–60	8	5	62	8	100
51–55	33	10	30	24	73
46–50	37	5	14	14	38
41–45	28	1	4	7	25
36–40	30	0	0	2	7
30–35	15	0	0	1	7
Total	155	25		60	

As an indicator of the moisture content of the air that would move into the area during the forecast period, the 2030 MST, minimum spread between temperature and dew point in the layer from 700 to 500 mb. at one of the various raob stations surrounding Salt Lake City, selected according to the 12,000-foot wind direction at Salt Lake City at 0230 MST, was used. After numerous trials the following raob stations were used for the various wind directions:

Direction	Station
S-SSW	Las Vegas
SW	Las Vegas and Ely*
W-WSW	Ely
WNW-NNW	Boise
N-ENE	Lander
E-SSE	Grand Junction

*Use arithmetic mean of the minimum spreads at these stations.

Actually there were no cases of measurable rain with WNW to NNW winds, as only relatively dry air moved in from the northwesterly quadrant. The wind direction was between N through E to SSE in only 8 cases out of 155, so the Lander and Grand Junction raobs were seldom used. The raob for Ely or Las Vegas was used for 133 out of the 155 cases.

The average height of the layer of maximum moisture was about 550 mb. (16,000 feet), suggesting that a better selection of the raob station might be made by using the wind for a level higher than 12,000 feet. However, winds at levels higher than 12,000 feet were missing too frequently to be of use in an objective forecasting method. In the few cases where the 12,000-foot wind was missing, the direction was estimated from streamlines at 12,000 feet drawn on the pibal chart.

An attempt was made to use the direction of the 700- and 500-mb. contour lines through Salt Lake City to indicate air flow, and thus which raob to select for moisture value. The attempt had to be abandoned because the height field over the Plateau in summer is fairly flat and the drawing of the contours is anything but objective. Also, the 0230 MST pibal has a decided advantage in being for a time 6 hours later than the time of the constant pressure charts.

The minimum temperature-dew-point spread in the 700- to 500-mb. layer correlated better with the occurrence of measurable rainfall than the average moisture value for the layer. This is probably because the moist tongue of air is usually of quite shallow depth when it first appears on the sounding, and frequently an average moisture value will not show a significant rise until too late to be of forecast value. Since the sounding used is 24 hours before the midpoint of the forecast period, the first indication of an increase in moisture is highly important. The use of 700- and 500-mb. dew points as indicators of moisture also proved inferior, because frequently the moist layer first appeared somewhere between these two constant pressure surfaces.

Table 2 shows the frequency distribution of rainfall occurrence with the minimum temperature-dew-point spread at any level between 700 and 500 mb. at the selected raob stations. Elevated surfaces other than 700 and 500 mb. gave poorer results. A comparison of table 2 with table 1 indicates the surface dew point to be the more significant variable for forecasting the occurrence of rainfall.

TABLE 2.—*Frequency of occurrence of measurable rainfall and trace or more with minimum temperature-dew-point spread in the 700- to 500-mb. layer at Las Vegas, Ely, Boise, Lander, or Grand Junction, selected according to the 12,000-foot wind direction at Salt Lake City.*

Minimum temperature-dew-point spread (°F.)	Total cases	0.01 inch or more	Percentage frequency	Trace or more	Percentage frequency
0–2	23	8	35	15	65
2½–5	41	11	27	25	61
5½–8	25	4	16	13	52
8½–11	15	1	7	2	13
11½–14	15	0	0	2	13
14½–17	10	1	10	2	20
17½–20 or more	26	0	0	1	4
Totals	155	25		60	

SCATTER DIAGRAMS

The scatter diagram used in making the forecast is shown in figure 1. As abscissa, it has the minimum temperature-dew-point spread in the 700- to 500-mb. layer at 2030 MST at Las Vegas, Ely, Boise, Lander, or Grand Junction, selected according to the 12,000-foot wind direction at 0230 MST at Salt Lake City; and as ordinate, the 0530 MST Salt Lake City surface dew point. For each day a plotted symbol indicates occurrence of no rain, a trace, a "dry" thunderstorm, or 0.01 inch or more precipitation during the 18-hour period 1130 MST to 0530 MST the following day. "Dry" thunderstorms (thunder heard but no rainfall reported at observing point) were included because frequently in these cases rain is observed to be reaching the ground in the immediate vicinity of the station. The line of best separation between measurable and nonmeasurable rain cases was drawn on the diagram by eye and its correctness of position checked by use of the skill score. (See Angell and Chen [6], for example.)

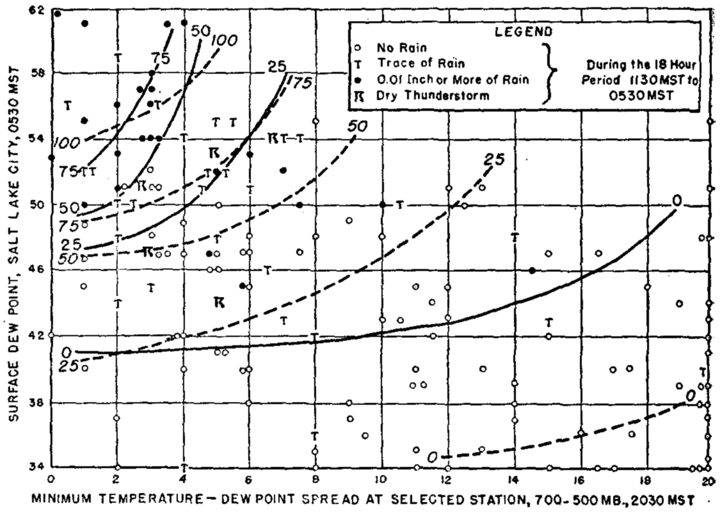

FIGURE 1.—Scatter diagram showing isolines of probability (percent) of measurable rainfall (solid lines) and of trace or more, including dry thunderstorms (dashed lines) at Salt Lake City for 18-hour period 1130 MST to 0530 MST the following day, during the months of July and August. See text, p. 149, for explanation of selection of raob station to be used in determining an abscissa value.

The maximum skill line was used as the 50 percent probability line, and 25 percent and 75 percent probability lines for the occurrence of measurable rainfall were also computed and drawn (solid lines). In addition, probability lines for a trace or more, including "dry" thunderstorms were drawn (dashed lines). These lines were computed in the following manner: The diagram was divided into boxes with an approximately equal number of points, and the percentage of observations with a trace or more of rain, and with 0.01 inch or more was computed for each box. Isolines were then drawn to fit the data, with a minimum of smoothing.

In an attempt to improve the forecasting skill of the method, a mean 700-mb. chart for 2030 MST on days preceding measurable rain cases at Salt Lake City was prepared and compared with a sample mean chart for the evening preceding no-rain days. A chart of height differences between the two mean charts was prepared (fig. 2), after the manner of Angell and Chen [6]. On the mean rainy-day chart, heights over the Pacific Northwest were much lower than on the mean no-rain chart. Also on the mean rainy-day chart, there was an east-southeasterly flow from the Gulf of Mexico into the southern Plateau, whereas on the mean no-rain map this moist air current was replaced by a northerly circulation over the west Gulf region, the mean position of the high-level anticyclone being shifted considerably westward. This latter feature is in fairly good agreement with Reed's observation [8] that when the high-level anticyclone is located west of

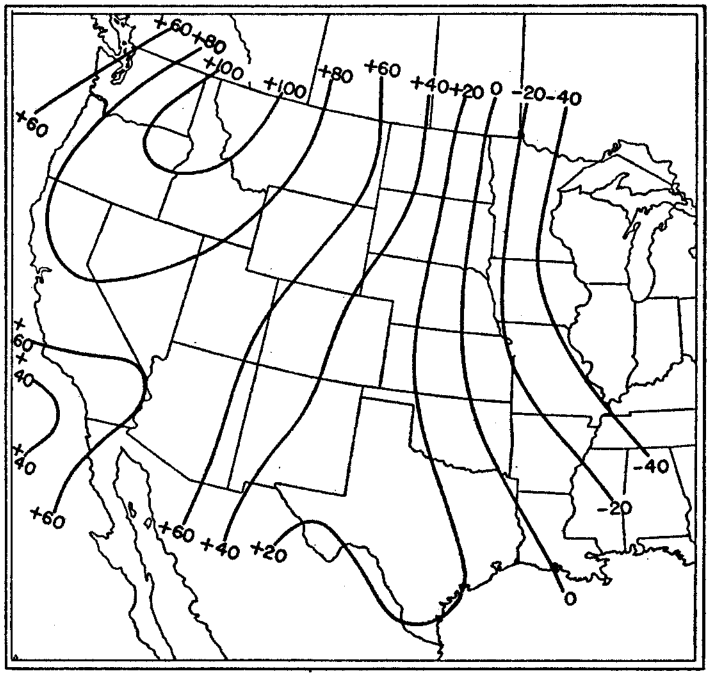

Figure 2.—Chart showing height differences (ft.) between mean 700-mb. no-rain chart and mean 700-mb. rain chart (no-rain chart minus rain chart).

the Continental Divide the southwest desert area is dry, but when to the east of the Divide, showers occur.

To make use of the centers of maximum difference between the two mean charts, a scatter diagram (not shown) was constructed using the 700-mb. height at Phoenix versus the height difference Spokane minus St. Cloud. Probability lines for the occurrence of measurable rain were drawn and this chart was then combined with figure 1 into a joint probability chart. However, this latter chart did not produce any higher forecasting skill scores on either the original or test data than figure 1 alone, so the latter was used as the final forecasting diagram. The lack of improvement in skill is probably because of the high degree of relationship between the differences in flow pattern of the two mean charts and the amount of moisture present at the southern Plateau raob stations. Either of these criteria alone shows considerable forecasting skill but the two apparently cannot be combined to increase the skill.

RESULTS FROM ORIGINAL DATA

Using the 50 percent probability line as the dividing line for the forecasting of occurrence or non-occurrence of measurable precipitation from the scatter diagram (fig. 1), results from original data are compared in table 3 with Weather Bureau staff forecasts recorded on Provional Forecast Rating forms. From this contingency table, skill scores and percentages of hits were computed. It may be seen that the skill score for the objective method was slightly higher than the score for the staff forecasts.

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Table 3.—*Contingency table for original data, showing comparison of objective forecasts with Weather Bureau staff forecasts*

		Objective forecast			Staff forecast		
		Rain	No-rain	Total	Rain	No-rain	Total
Observed	Rain	17	8	25	13	12	25
	No-rain	6	124	130	3	127	130
	Total	23	132	155	16	139	155

Objective method: Skill score 0.66; percentage hits 91.
Staff forecasts: Skill score 0.58; percentage hits 90.

A few of the measurable rain cases fell well outside the 25 percent probability line on the scatter diagram. These were investigated individually. Most of the errors were caused by moist air at fairly high levels (about 16,000 feet) moving so rapidly from the south into the Salt Lake area that this moisture was not in evidence at any of the immediately surrounding raob stations at 2030 MST the previous evening. This type of failure is due mainly to the large time lag between the latest available upper air data and the time of making the forecast.

There were a few cases where the probability of precipitation was fairly high yet no measurable rain occurred. In some of these failures, a trough passed Salt Lake City shortly after 0230 MST, bringing in drier air from the northwest. If the trough should pass before the forecast is issued at 0900 MST, the forecaster can, of course, subjectively improve the objective forecast by taking this factor into consideration.

RESULTS FROM TEST DATA

Skill scores and percentages of hits were also computed for the three months of test data from the contingency table shown as table 4.

Table 4.—*Contingency table for test data, showing comparison of objective forecasts with Weather Bureau staff forecasts*

		Objective forecast			Staff forecast		
		Rain	No-rain	Total	Rain	No-rain	Total
Observed	Rain	6	6	12	8	4	12
	No-rain	5	76	81	6	75	81
	Total	11	82	93	14	79	93

Objective method: Skill score 0.45; percentage hits 88.
Staff forecasts: Skill score 0.55; percentage hits 89.

The skill score of the objective method falls somewhat below staff results. This is possibly due to the limited data available in computing the original line of maximum skill. With more years of data available, the skill scores of the original and test data would probably tend to approach each other more closely.

CONCLUSIONS

The objective method of forecasting midsummer precipitation at Salt Lake City compares favorably with Weather Bureau staff results in both skill scores and percentage hits. Undoubtedly there are some pertinent variables which have not been tested, particularly stability parameters, and it is possible that higher skill may yet be obtained by graphically combining scatter diagrams of these yet untried variables with those already tested.

In actual use, the scatter diagram may be helpful in a way not yet mentioned. The probability lines for a trace or more were added to the scatter diagram because it was believed that they would prove useful in forecasting very light or scattered showers, or showers over the nearby mountains, when the probability of a trace or more was 50 percent or greater, but the probability was less than 50 percent for measurable rainfall. On the other hand, when the probability of measurable precipitation was 50 percent or more, the forecast could then simply indicate showers, or possibly moderate to heavy showers. In its present form, the method is simple, quick to use, and almost completely objective. As already indicated, subjective improvements may be made by the forecaster under certain conditions.

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